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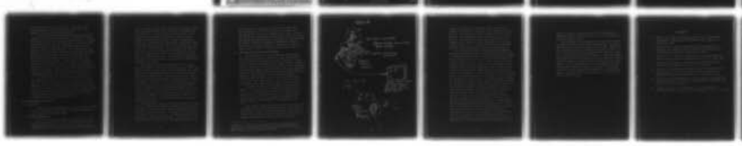

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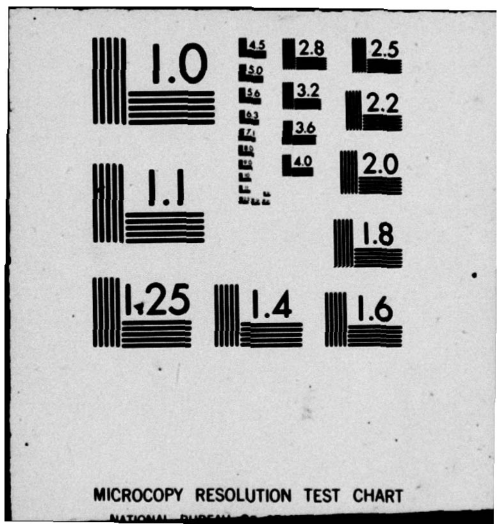
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS
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CAMBRIDGE, MASSACHUSETTS 02139

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APPLICATIONS FOR AERIAL PHOTOGRAPHY FOR HYSURCH

by

(10) A. C. Conrod

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EXPLANATORY NOTE

This is one of a series of Engineering Reports that document the back-ground studies to be used in a system design for HYSURCH (Hydrographic Surveying and Charting System). In general, these reports cover more detail than that finally necessary for a system design, Any subsystem recommendations contained in these reports are to be considered tentative. The reports in this series are.:

RN-22	Soundboat Navigation Equipment and Strategy for HYSURCH by John Hovorka
RN-23	The Role of the HYSURCH Survey Ship in the Production of Nautical Charts by Edwin A. Olsson
RN-24	An Investigation of Side-Looking Radar and Laser Fathometers as HYSURCH Sensors by Jack H. Arabian
RN-25	A Computation Center for Compilation, Revision and Presentation of Hydrographic Chart Materials by Edwin A. Olsson
RN-27	Parameters for the Evaluation of Sonar Depth Measurement Systems by Joel B. Searcy
RN-28	Tidal Measurement, Analysis, and Prediction by J. Thomas Egan and Harold L. Jones
RN-29	Applications of Aerial Photography for HYSURCH by A.C. Conrod
RN-30	Sounding Equipment Studies, by Leonard S. Wilk

RN-31 Error Analysis of a Dual-Range Navigation Fix and Determination of an Optimal Survey Pattern by Greg Zacharias

RN-32 Tethered Balloons for Sounding Craft Navigation Aids by Lou C. Lothrop

These reports were prepared under DSR Contract 70320, sponsored by the U.S. Naval Oceanographic Office Contract Number N62306-67-C-0122. The reports are meant to fulfill the reporting requirement on Sub-system selection as specified in the MIT proposal submitted in response to the Oceanographic Office Request for Quotation, N62306-67-R-005.

I The Role of Aerial Photography in Hysurch

1. General

The principal use of aerial photography in Hysurch will be to provide positioning information for locating navigation aids, shoreline delineation and under-water information—as well as the usual mapping and reconnaissance data.

Some of the photography will have to be obtained from existing operating divisions of the Navy, especially high altitude coverage, and some work may have to be done apart from the Hysurch survey team effort if weather conditions dictate. Chapters ~~II & III, below~~ contain comments on the procurement and use of high and low altitude photography.

2. Comments on Aerial Photography

The example given in the preliminary report (Ref. 1) showed the results which could be obtained when locating a reference marker some distance at sea, when photographing from a high altitude. At low altitudes, the use of horizontal-looking cameras, in a method similar to that reported as being used by USC & GS, will be required. For this, and all photography in which terrestrial or ocean-surface object locations is the aim, the recommended film is black-and-white high-speed infrared, such as Kodak 5424. With the low-content resolution of 28 lines/mm quoted by the maker for this film, we would achieve an angular resolution of 1.41 milliradians per inch of focal length. For Plus-X film of resolution 40 lines/mm, the angular resolution would be 1.0 milliradian per inch, but the inferior haze-penetrating properties of panchromatic film might not allow full use of its resolution at medium-to-long ranges. Shore-line photography, for mapping purposes, is usually done at the time of low water. Obviously this will not always be possible in the given time span. The decisions involved in whether and how to get coastal maps from photos

are arbitrary - and dependent on the circumstances of individual survey missions. About the only thing that is certain is that, again, infrared film is the obvious choice for this task. Color I-R, such as Kodak 8443, should be used whenever possible. The advantages of color have been stated so often, and so decisively, that it is not necessary to justify its use here. (Refs. 2,3 4)

Underwater features can be detected, and bathymetric data obtained, if one is fortunate enough to have adequate light and reasonably transparent water. Again, it is a "method of opportunity" rather than a dependable technique. Of the presently available films, we would recommend Ansco D-200, and suggest that D-500 be evaluated at the first opportunity. The Key West experiments, AF Project 67-3 (Ref. 5), and MIT's Bahama Banks tests (Ref. 6), have both verified the advantages of the Ansco color emulsions over Kodak products for photography through sea water.

3. Underwater Photography

The use of underwater photography for photogrammetry and surveying is, while not new, an undeveloped tool that deserves investigation for application to the Hysurch problem. Underwater photography appears capable of providing bottom contours and bottom composition data, if properly applied (Ref. 7).

For Hysurch the principal problem will be the design of camera housing that are usable at the design speeds of the boats. If it is possible to design these so that there is not cavitation in front of the camera ports, there appears to be no reason why we cannot expect to use underwater cameras for such purposes as obstacle location and measurement, and bottom type determination. There is a wide selection of cameras, television systems and light sources available on the open market.

II High-Altitude Photography for Hysurch

1. General

We have assumed, in this discussion that conventional high-altitude reconnaissance and mapping photography will be available from sources outside of Hysurch, so the comments below are restricted to two specific cases: the ground resolution aspects of marker-buoy and shoreline-feature photographs, and the use of infra-red photography for shoreline determination.

2. Ground Resolution of High-Altitude Photography

The stated accuracies for Class B maps are 0.04 inches, independent of map scale. This becomes 40' on a map scale of 1:12,500 and increases to 160' in 1:50,000 maps. To relate this to the photos from which the maps may be made, or revised, let us take an extreme case. (The films which will probably be used for most of the Hysurch work are shown in Table I.)

Assume a camera of 3" focal length on an aircraft flying at 50,000 feet. The lens resolution can be assumed to be so high that the film resolution is the only limiting factor on image quality. In Table I, the lowest resolution tabulated (for Kodak 8443 film) is 22 lines/mm. The scale of the photography for the conditions stated is 1:200,000 (0.25' : 50,000). The photographs would have to be enlarged by 16X to bring them to 1:12,500 scale, and the enlargement would have (assuming no errors in the projection process) a resolution of 1.37 lines/mm, which is equivalent to a map accuracy of 0.029 inches. This is within the tolerances quoted for the maps. More practical cases leave more comfortable margins. When the necessary considerations of camera lens resolution, enlargement distortion, and processing and handling errors are dealt with, almost any camera/film combination that might be

used will prove adequate for mapping and map revision, within the limits mentioned in Ref. 1 the location of navigation buoys from high-altitude photography. In the example given there, it was assumed that the film and camera parameters could be ignored. The same problem will be re-examined here in terms of the actual performance specifications of existing films and cameras.

Before beginning a sample problem, let us digress for a moment to the subject of black and white vs. color for general photo coverage. As we mentioned earlier, there is almost universal agreement on the superiority of color film over black and white for mapping and reconnaissance. The use of color provides the photo-interpreter with such additional information that all of his tasks are simplified. Even in instrumental analysis of films, color provides data that the best black and white film cannot supply. (The one important exception is in resolution. There are black and white films that are capable of 1000 lines/mm, but this is far beyond the requirements of Hysurch's purposes.)

Table I shows that the film speeds and the resolutions of modern high speed color emulsions are of the same order as black and white films. Of themselves, these facts suggest that the performance of color films will be as good as black and white; in fact, they are sometimes superior, for in cases where target contrasts are marginal for black and white images, there is often a color difference that allows differentiation of very similar objects. The case where black and white (or black and white infrared) films are superior to color is where the atmospheric haze conditions demand that filters be used. If we have to go, for example, to a #25 filter (deep red) there is no advantage to be gained in using color, since only a part of one dye-layer will be effective, and the red-sensitivity of black and white pan film is extended 30 to 40 mu further into the red than the red-dye layers of conventional color film.

[The films which will probably be used for the majority of Hysurch work are shown in Table I, below]

Film Type	Aerial Exposure Index	Res Power TOC 1.6:1	Uses
EK Plus X Aerographic Type 5401	80*	40 1/mm 1 mr/in. of focal length	General purpose, black
EK Infra Red Aerographic Type 5424	125**	28 1/mm 1.43 mr/in.	Haze penetration and special purpose recon.
EK Ektachrome Aerographic Type 8442	25	28 1/mm 1.43 mr/in.	Medium to High Alt. Color Film
EK Ektachrome MS SO-15	6	40 1/mm 1.0 mr/in.	Low Alt. mapping, color
EK Ektachrome IR Type 8443	10	22 1/mm 1.82 mr/in.	Camouflage detection and differentiation of terrain and cover
Ansco D-200	200*	40 1/mm ♂ 1.0 mr/in	High Speed, general purpose color-good for underwater work

* ASA Speed　　** ASA Speed - No filter　　♂ TOC = 2:1

A typical camera for high altitude reconnaissance aircraft (i.e. the RA-5C) would be the Wild RC-8 or Fairchild KC-4, with 6" Super Aviogon or Geocon I (or IV) lenses. It is recommended that only these, or similar fully color-corrected lenses be used to allow full use of color films. We may assume a conservative figure of 100 lines/mm for either of these lenses.

Refer to the parameters in the example in Ref. 1;

1. Altitude = 50,000 Ft.
2. Contrast = 2:1 on ground; i.e., >1.6:1
3. Shoreline to buoy = 8 n.mi.

We would like to determine (1) the size of the buoy required and (2) the ground resolution on shore, bearing in mind that if 50,000 feet is taken as a maximum flight level, the numbers we get will be a maximum and a minimun respectively.

Using the simplified calculation

$$\frac{1}{R_{image}} = \frac{1}{R_{lens}} + \frac{1}{R_{film}}$$

The image resolution will be approximately 22 lines/mm. for Ektachrome Aero 8442, with a 100 l/mm lens. Then, the smallest identifiable image on the film will be about 0.02 inches across. That means that, with a scale of 1:100,000, a buoy would have to be sixteen feet across to be seen. The minimum ground resolution of objects ashore would be the same. (For Plus-X film, R_{film} = 40 lines/mm, the buoy size and ground detail dimensions would be about 12 feet for an R_{image} of 28.5 l/mm).

A curve, Fig. 1, shows the minimum buoy size for Ektachrome 8442 and Plus-X Aerographic 5401 films, with a 6", 100 l/mm lens, vs aircraft altitude. Remember that the buoy-to-shore distance will be determined by the angular coverage of the camera and the altitude of the airplane. The 8 n.m. distance of the original example, therefore,

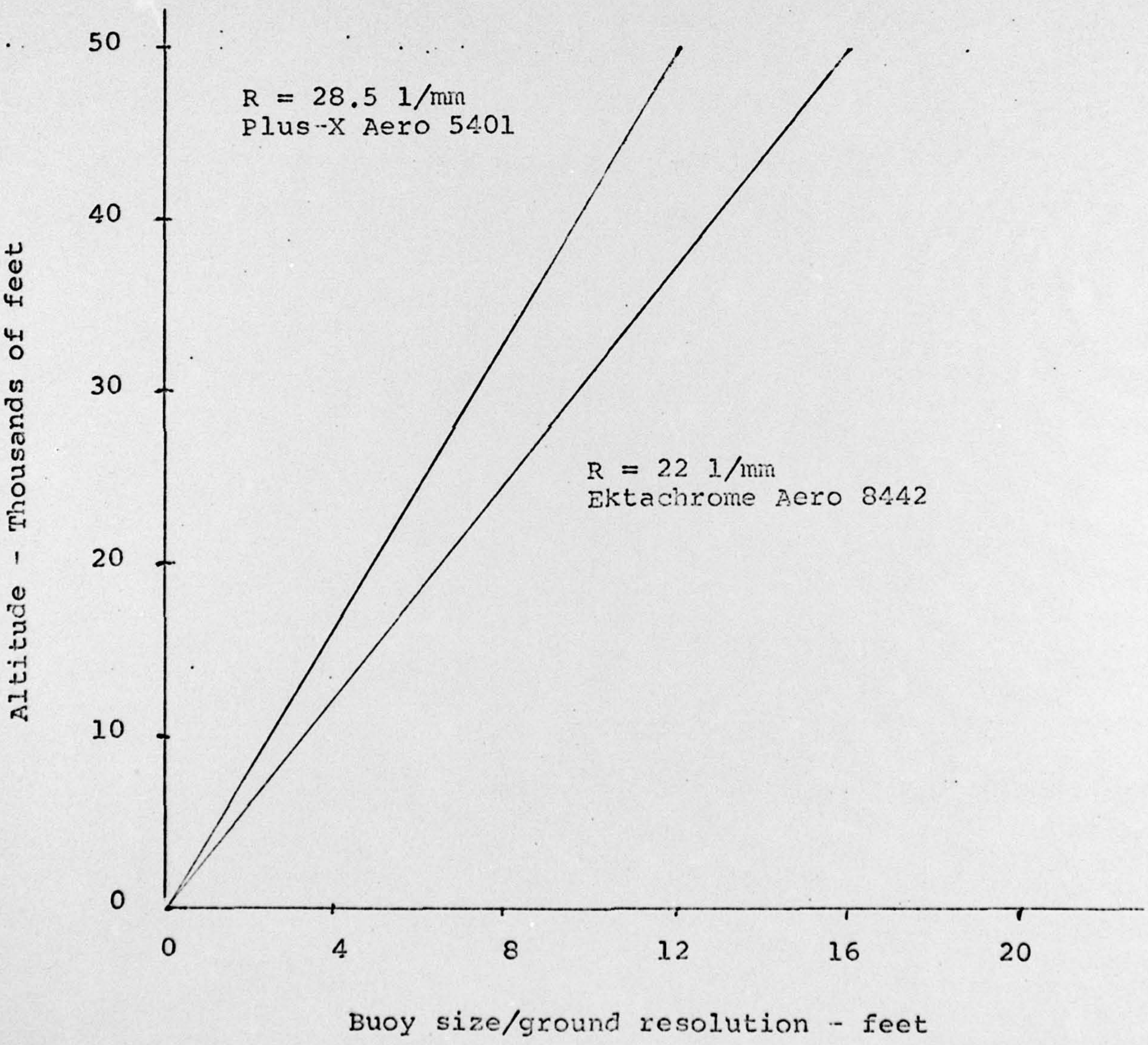


Fig. 2 Buoy size/ground resolution vs altitude for two lens/film resolutions, with 6" focal length lens.

no longer holds. A good rule of thumb is to assume that the maximum buoy-to-shore distance will be about equal to the altitude, as would be the case for a 6" lens, $9\frac{1}{2}$" film, camera half angle = 37° and both buoy and shoreline appearing on a single frame. Since the ground resolution is directly related to lens focal length, it is a simple matter to adjust any of the preceding numbers for larger focal lengths.

3. Shoreline Photography with Infrared Film

While this section has been placed under the general heading of high-altitude photography, the statements that are made can be applied to infrared photography from any vantage point.

The optical properties of water in the near infrared makes it appear nearly black on black and white infrared film, and a deep blue on color infrared film. Only a few millimeters of water are required to obscure bottom detail, a feature which has been used to advantage by the USC&GS in aerial-photographic determination of mean-low-water shorelines. (Ref. 2) Most of this work has been done in black and white, but color is equally usable, and offers added benefits, as mentioned below.

The data in the preceeding section, in resolution and ground detail, apply equally to infrared photography. It is probably worth repeating that camera lenses must be color-corrected and capable of providing an adequate infrared focus, so that Aviogon- or Geocon-quality optics are essential.

The performance of infrared color film has proven to be something less than predictable, and is obviously more sensitive to exposure factors than the manufacturers' film data suggest. As far as Hysurch is concerned, this means only that there may be some water penetration visible on the images (depending on incident light, water clarity and bottom reflectivity) when one would expect none. The actual shoreline, though, will be clearly defined.

The surf-line might be a problem in a few cases, with some ambiguity in the wet sand-surf-water zone. This should be checked with field experiments.

If the ground resolution permits, there are certain things we can look for for shoreline information. One is the bottom-growing plants of the inter-tidal zone. If they are visible through the red chlorophyll images they leave on color infrared film, one can approximate the tidal stage at the time of photography. The appearance of the shore between dry land and wet sand can indicate the range of high tide in the area. Discolored water near or off shore will show suspended material that may have been stirred up from the bottom, or carried out in river or waste system discharges. The distribution of pollutants discharged from a known point will provide information on currents off shore. Color infrared film was once known as camouflage detection film, and that statement needs no amplification as far as its use on land is concerned.

The chief restriction on color infrared film is the one already mentioned in Ref. 1: a light level of about 3000 ft-candles is necessary for good photography. This condition can be circumvented to some extent by using long exposures and larger apertures, but vehicle motion and lens sizes will usually preclude them. Reciprocity-effects of long exposures are not known, but should not be a major problem at speeds up to 1/2 second or so.

III Low Altitude Photography

1. General

The low-altitude photographic problem will be considered for two special cases; stereo for depth determination, and bridging from point to point.

2. Stereo Photography

Of the three possible methods of photographic determination of water depth (stereo, image density, and wave photography) only stereo is known to be accurate. On smooth bottoms, we can expect to get a vertical resolution

of 1 to 2 feet per 1000 feet of airplane altitude. Where there are identifiable bottom details, 1 foot/1000 feet is attainable. For the depth accuracies stated in the Hysurch work statement, $\pm$ 1 1/2 feet, stereo coverage should be taken at about 1500' altitude. Depending on local water conditions and light levels, underwater photography might be taken with color film, or with black and white film with filtering. If light levels are 3000 Ft-c or higher. Color or narrow-band black-and-white can be used. At levels below 3000, but above 1000 Ft-c, black-and-white film will be best. Photography for underwater features should generally not be attempted at light levels of 1000 Ft-c or lower.

The best bottom-feature definition is to be found with sun angles of about 30° above the horizon, while the best underwater illumination will be found when sun angles are as high as possible before surface glitter obscures photographic image detail. Camera viewing angles should be as near vertical as possible, especially in the higher sea states. Generally, even bright cloudy days will provide only half the water penetration of direct sunlight. Night photography with high-intensity flares has been attempted over the water, and flares or flash bombs could be used for supplemental lighting. Night work with artificial light might be more successful than work under cloudy daytime skies, and some experiments in this field would be worthwhile.

The selection of photo-interval for stereo is straightforward. Standard 60% overlap is probably the best type of coverage, unless one needs special stereo pairs of some particular area of interest. The vehicle will determine the type of camera to be used. For low speed aircraft or helicopters, still cameras are best. For high speed air craft, stereo strip cameras are the obvious choices. In

view of the wide variety of cameras of all types that are available, it is best to refrain from making any recommendations here as to manufacturer or type. Instead, the readers are referred to a compilation of camera and system specifications contained in AF Systems Command Document RC 013200, "Airborne Photographic Equipment" prepared by Data Corp. for Recon Central, WPAFB, Dayton, Ohio, and especially to Tables I through VI at the end of Vol. I.

3. Low-Altitude Navigation-Aid Location

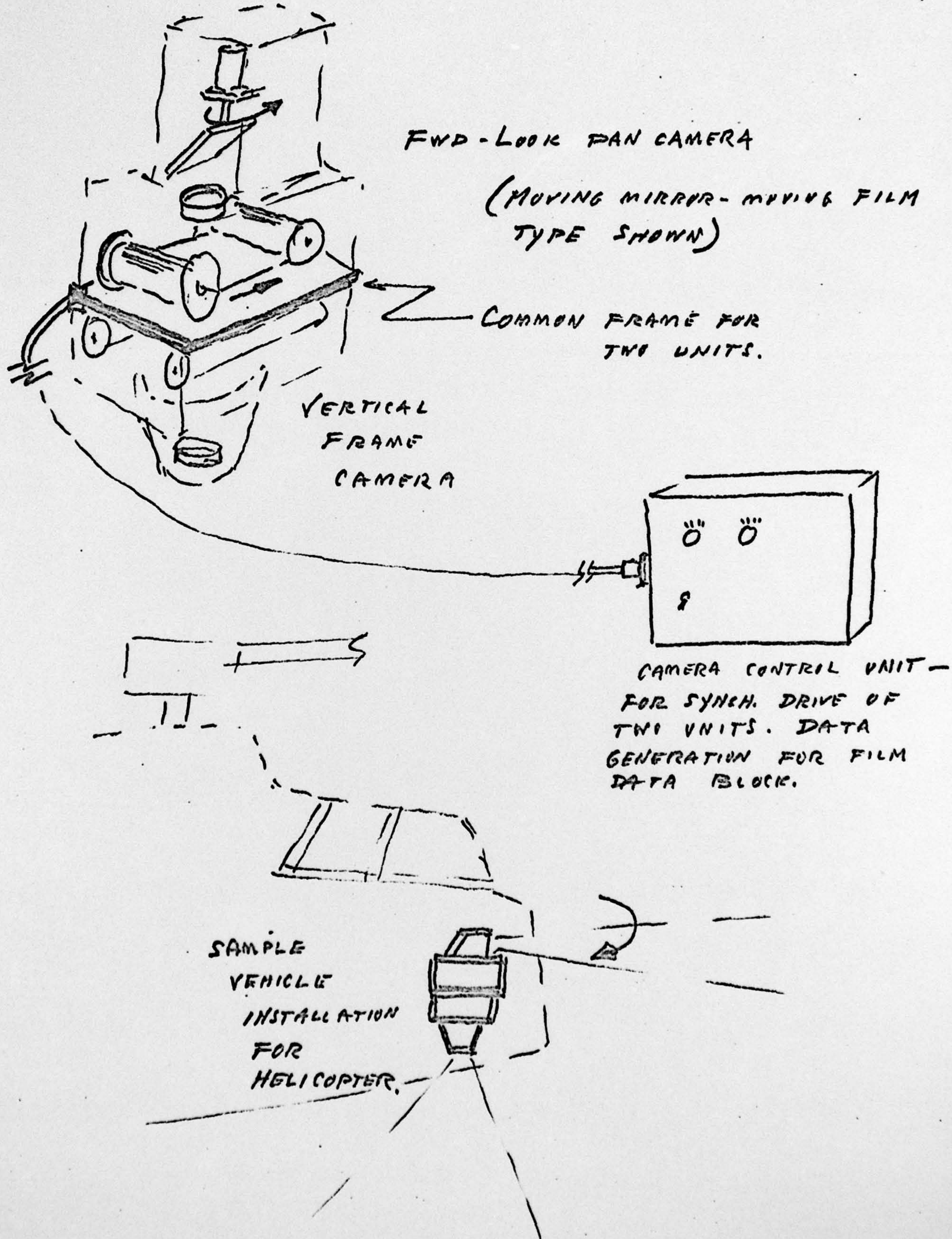
In low-altitude vertical photography, using other than vertical panoramic cameras*, it will be necessary to take multiple photographs to obtain coverage of large areas. Using these photographs to locate distant features, such as a buoy or off-shore rocks relative to the shoreline, will require carrying measurements over as many sequential photos as are required to cover the space between points of interest. This process, the "bridging" of a space, cannot be done if there are areas of featureless water in the line under construction. Some suggested methods of bridging over water are discussed in this section.

The term "low altitude" is taken as 2,500 feet or lower. It is assumed that horizontal visibilities are over 3 mi. in the visible, and 10 mi. in the red and infrared (i.e., above VFR minimums, and infrared photography to within 3° of the horizon is possible.) The data in Table I will be used for the examples cited below.

One suggested method of tying a buoy to the shore is a modification of a technique described as being used by the USC&GS, in which a helicopter locates other objects relative to itself by vertical orientation relative to a marker, simultaneously taking horizontal bearings. A

* Even with a 180° pan camera, when working from low altitudes the distances covered on a single frame will be limited by atmospheric haze - especially in the marine coastal environment, where water and aerosol particles abound.

Figure 2


FWD-LOOK PAN CAMERA
(MOVING MIRROR-MOVING FILM TYPE SHOWN)
COMMON FRAME FOR TWO UNITS.
VERTICAL FRAME CAMERA
CAMERA CONTROL UNIT— FOR SYNCH. DRIVE OF TWO UNITS. DATA GENERATION FOR FILM DATA BLOCK.
SAMPLE VEHICLE INSTALLATION FOR HELICOPTER.

two-camera system is recommended, both for permanent records and to relieve the pilot of the chores of precise piloting and observations under possible adverse circumstances. The speed with which a photograph may be taken, once the vehicle has been positioned, may also be an advantage when weather or other conditions are a problem. A sketch of the type of camera required for simultaneous vertical and horizontal photography is shown in Fig. 2.

The illustration shows a two-camera device where a horizontal panoramic camera, of any desired angular sweep is mechanically joined with a vertical-looking still camera. The principal axes of the two cameras are determined, by the manufacturer in test so that they are known to a few seconds of arc. Then when both cameras are fired in such a manner that the time of exposure of the vertical camera is known in terms of the aiming angle of the horizontal camera, we can relate the scenes recorded by the two images, and determine the locations of the objects in the two photographs relative to each other. To summarize and re-phrase the foregoing, if we have two cameras, whose optical axes are at known directions relative to each other, we can find the relative locations of objects appearing on the two photographs, if we know the altitude of the vehicle (or the range to any object in either the horizontal or vertical photos). The absolute orientation cannot be determined unless an adequate length of sea horizon is included in the horizontal camera image. A more reliable way of determining orientation would be to have, at the least, a bubble level image on a data block in the photos, or to make use of an on-board vertical reference to stabilize the cameras or to provide orientation information that is presented in data blocks on the film. A data generator such as the AN-ASQ-90 auxiliary data annotating set can be installed in either the horizontal or

vertical camera for putting on up to 186 bits/exposure (including parity and index bits) from clocks, altimeters, vertical platforms, etc.

The bridging from one photo to the next would be done by measuring linear distances between features on photos and converting these into angles to get range. Either the actual distance between the features has to be known, or the initial range has to be determined by getting an image of a marker buoy on the vertical camera. Errors in range determination will be proportional to the separation between selected landmarks ashore, and will decrease as the range closes. For an hypothetical 3" forward looking pan camera, using medium resolution film, we can predict an angular error from linear measurement uncertainty, of 0.84 milli-radian. This will result, very roughly, in an error of 1 part in 1000 in range.

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